HIGH STRENGTH MULTI-COMPONENT ALLOY

BACKGROUND OF THE INVENTION

Field of Invention

The present invention relates to a multi-component alloy, and particularly relates to a multi-principal-element alloy that has high strength at high temperature.

Related Art

An alloy is made by mixing at least one metal element with one or more metal elements or one or more non-metals. The alloy formed of two kinds of element is called a binary alloy. Similarly, the alloy formed of multiple kinds of element is called a multi-component alloy. Typically, the alloy is based on one or two principal (or main) metal elements. If the alloy is based on Fe, then the alloy can be called a Fe-based alloy, which widely includes steel materials such as alloy steel, tool steel and high-speed steel. If the alloy is based on Al, then the alloy is called an Al-based alloy, which is also well developed. Specially, the superalloy has been widely used in various fields includes Fe-based alloy, Co-based alloy, and Ni-based alloy. Conventionally, the alloy contains more than 40 atom% of the main element(s) based on the total number of atoms of the alloy and the balanced amount of other elements. The above alloying design concept limits the freedom of formulation for the alloy and its applications.

The temperature at which the alloy can be used is a main concern when selecting a high temperature alloy. For example, carbon steel or low-alloy steel is suitable for temperature lower than 370℃. Stainless steel is usually used at a temperature lower than 425℃. The strength of this type of alloy rapidly deteriorates as the temperature increases. Especially when the temperature gets higher than 500℃, the strength of this type of alloy is almost lower than 200MPa, which greatly limits its applications. The superalloy can be

used in high temperature environment, for example, at the temperature higher than 540℃. Within certain ranges of temperature, the strength of the superalloy is not adversely affected as the temperature increases. The common superalloy used in high temperature environment includes Ni-based superalloy and Co-based superlloy. The Ni-based superalloy is usually used for products which need high strength at high temperature. The Co-based superalloy exhibits high strength at high temperature of 730-1100℃. Such types of alloy has more than 400MPa of yield stress at 800℃ after being forged. The superalloy is typically based on a single main element such as Ni or Co, in amount of 45-75 atom%. Secondary elements such as chromium, cobalt, nickel, molybdenum, tungsten, niobium, titanium, aluminum, iron, manganese, silicon, carbon, boron, zirconium and vanadium are optionally added in the alloy to further modify the alloy characteristics for high temperature use. Such alloys with single main element content have been well developed. However, it is hard to further improve their high temperature strength with the currently known compositions.

SUMMARY OF THE INVENTION

In order to produce a multi-component alloy with good high-temperature mechanical properties, the invention provides a high-strength alloy that contains multi-principal multiple elements and is formulated under a design concept different from the prior art. The amount of each main element of the alloy of the invention is in the range of about 5 to 35 atom% based on the total number of atoms of the alloy. The multi-component alloy of the invention has high strength at high temperature.

In order to achieve the above and other objectives, the multi-component alloy of the invention contains Fe, Co, Ni, Cr, Cu and Al as main elements. Each main element of the alloy is in the range of about 5 to 35 atom% based on the total number of atoms of the alloy. It has been experimentally proved that the alloy of the invention has high strength at high temperature. The multi-component alloy therefore provides higher freedom for alloy design. Furthermore, the content of each component can be adjusted as desired.

The invention further provides a high strength multi-component alloy containing 13-19 atom% Fe, 13-19 atom% Co, 13-19atom% Ni, 13-19atom% Cr, 13-19atom% Cu, and 5-35atom% Al, based on the total number of atoms of the alloy. Furthermore, the multi-component alloy can be produced by the conventional alloy production process and melting process, such as electrical melting, induction melting, arc melting, plasma melting, electron beam melting, powder metallurgy, rapid solidification, and mechanical alloying in an atmospheric, protective or vacuum environment.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given herein below illustration only, and thus are not limited of the present invention, and wherein:

FIG. 1 is a graph illustrating the relationship between the yield stress and the temperature according to examples 1-3 of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The multi-component alloy mainly contains Fe, Co, Ni, Cr, Cu and Al elements. Each of theses elements is in the range of about 5-35atom% based on the total number of atoms of the alloy to impart the multi-component alloy which has excellent

high-temperature mechanical properties.

Table 1 shows elements and contents of a multi-component alloy according to various examples (e.g. example 1 to example 3) of the invention.

Table 1

Alloy No.	Content of each main element of the multi-component alloy (atom%)					
	Fe	Co	Ni	Cr	Cu	Al
Example 1	18.2	18.2	18.2	18.2	18.2	9
Example 2	16.7	16.7	16.7	16.7	16.7	16.5
Example 3	14.3	14.3	14.3	14.3	14.3	28.5

In the example 1, the multi-component alloy contains 18.2 atom% Fe, 18.2 atom% Co, 18.2 atom% Ni, 18.2 atom% Cr, 18.2 atom% Cu and 9 atom% Al.

In the example 2, the multi-component alloy contains 16.7 atom% Fe, 16.7 atom% Co, 16.7 atom% Ni, 16.7 atom% Cr, 16.7 atom% Cu and 16.5 atom% Al.

In the example 3, the multi-component alloy contains 14.3 atom% Fe, 14.3atom% Co, 14.3 atom% Ni, 14.3 atom% Cr, 14.3 atom% Cu and 28.5atom% Al.

About 2000g of raw material is formulated according to the compositions shown in Table 1 and melted in a vacuum induction furnace. Then, the melt is poured in a copper mold and solidified to form a cast bulk. The cast ingot is cut and machined to produce a plurality of cylindrical rod of 10mm in diameter, 15 mm in height.

Vicker's hardness values for the alloy rod samples are measured by using Matsuzawa Seiki MV-1 Vicker's hardness tester under the conditions of 5kg of load, 70μm/s of loading speed, and 20 seconds of loading duration.. The samples are ground respectively with silicon carbide sand papers 180#, 240#, 400#, 600#, 800#, 1200# before testing. Mean value of hardness measures taken at 7 different locations is calculated to estimate Vicker's hardness for each alloy sample. Vicker's hardness measures of the examples 1 to 3 are

HV208, HV406 and HV566, respectively.

The alloy rod samples of examples 1-3 then undergo high temperature compression in a Gleeble 2000AA dynamic thermal-mechanical simulator. 0.2% offset of yield stress is obtained. The high temperature compression test is performed by heating the alloy sample to a test temperature at 10℃/sec and then keep the test temperature for 2 minutes to obtain a constant interior temperature. Then, a test under conditions of 10 s^{-1} of strain rate, and 300-1200℃ of test temperature is performed. FIG. 1 is a graph illustrating the relationship between the yield stress and the temperature according to examples 1-3 of the invention. In each of the examples 1-3, only the content of aluminum differs. From the results of example 1-3, it is found that the yield stress increases as the content of the aluminum increases, and the yield stress at a temperature lower than 800℃ is larger than 400MPa. Besides, the invention provides a high strength multi-component alloy containing 13-19atom% Fe, 13-19atom% Co, 13-19atom% Ni, 13-19atom% Cr, 13-19atom% Cu and 5-35 atom% Al.

The yield stress of the example 1 is not significantly changed with a variation in temperature between 300 and 800℃. That is, the yield stress is not greatly reduced as the temperature increases. When the test temperature in the example 2 is 900℃, the yield stress obtained is larger than 400MPa. When the test temperature in the example 3 is 1100℃, the yield stress is also larger than 400MPa. From the results shown in FIG. 1, the high strength multi-component alloy exhibits excellent mechanical performance in high temperature environment, compared to conventional heat-resistant stainless steel and superalloy.

In the following example 4 to example 8, the content of one of the main elements is varied while the others are similar. The main elements and ratios of the multi-component alloy are listed in the following Table 2.

Table 2

Alloy No.	Content of each main component of the multi-component alloy (atom%)					
	Fe	Co	Ni	Cr	Cu	Al
Example 4	9	18.2	18.2	18.2	18.2	18.2
Example 5	18.2	9	18.2	18.2	18.2	18.2
Example 6	18.2	18.2	9	18.2	18.2	18.2
Example 7	18.2	18.2	18.2	9	18.2	18.2
Example 8	18.2	18.2	18.2	18.2	9	18.2

In the example 4, the multi-component alloy contains 9 atom% Fe, 18.2 atom% Co, 18.2 atom% Ni, 18.2 atom% Cr, 18.2 atom% Cu and 18.2 atom% Al.

In the example 5, the multi-component alloy contains 18.2 atom% Fe, 9 atom% Co, 18.2 atom% Ni, 18.2 atom% Cr, 18.2 atom% Cu and 18.2 atom% Al.

In the example 6, the multi-component alloy contains 18.2 atom% Fe, 18.2 atom% Co, 9 atom% Ni, 18.2 atom% Cr, 18.2 atom% Cu and 18.2 atom% Al.

In the example 7, the multi-component alloy contains 18.2 atom% Fe, 18.2 atom% Co, 18.2 atom% Ni, 9 atom% Cr, 18.2 atom% Cu and 18.2 atom% Al.

In the example 8, the multi-component alloy contains 18.2 atom% Fe, 18.2 atom% Co, 18.2 atom% Ni, 18.2 atom% Cr, 9 atom% Cu and 18.2 atom% Al.

Vicker's hardness values of the multi-component alloys according to the examples 4 to 8 are obtained in the same way as in the examples 1-3. The results are listed in the following Table 3.

Table 3

Alloy No.	Vicker's hardness
Example 4	HV418

Example 5	HV473
Example 6	HV423
Example 7	HV367
Example 8	HV458

Vicker's hardness values of the examples 4 to 8 are higher than HV208 of the example 1. The multi-component alloy according to the invention having a considerably wide content range exhibits high hardness.

Furthermore, under the design concept of the multi-component alloy according to the invention, no more than 4.5 atom% of secondary elements other than the main elements, based on the total number of atoms of the alloy, can be added to the alloy to further modify the composition as desired. Examples of secondary elements include molybdenum, tungsten, niobium, tantalum, scandium, titanium, vanadium, manganese, zirconium, boron, carbon, nitrogen and silicon.

The following Table 4 shows ingredients of the multi-component alloy according to the invention and Vicker's hardness values of alloy samples produced from the multi-component alloy.

Table 4

Alloy No.	Content of each main component of the multi-component alloy (atom%)							
	Fe	Co	Ni	Cr	Cu	Al	Other elements	Vicker's Hardness
Example 9	17.5	17.5	17.5	17.5	17.5	8.8	3.5 B	HV347
Example 10	17.5	17.5	17.5	17.5	17.5	8.8	3.5 Si	HV266
Example 11	17.5	17.5	17.5	17.5	17.5	8.8	3.5 Mo	HV220
Example 12	18.5	18.5	18.5	18.5	18.5	5.6	1.9 C	HV210
Example 13	27.8	13.9	13.9	13.9	13.9	13.9	2.7 C	HV287

Example 14	15.9	15.9	31.8	15.9	8	8	4.5 C	HV305

It will be apparent to the person skilled in the art that the invention as described above may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.